TITLE: Analysis of 13 years of Cassini/VIMS and first JWST observations of Titan: Global mapping of Titan's surface reflectivity in the near-infrared and preparatory study of the future Dragonfly mission.

PhD supervisor: **Rodriguez Sébastien, MCF, HDR, rodriguez@ipgp.fr**

Laboratory: **Planetary and Space Science – Institut de Physique du Globe/Université de Paris UMR7154**

Financing: **Doctoral contract with or without teaching assignment**

Presentation of the subject: (Maximum 2 pages)

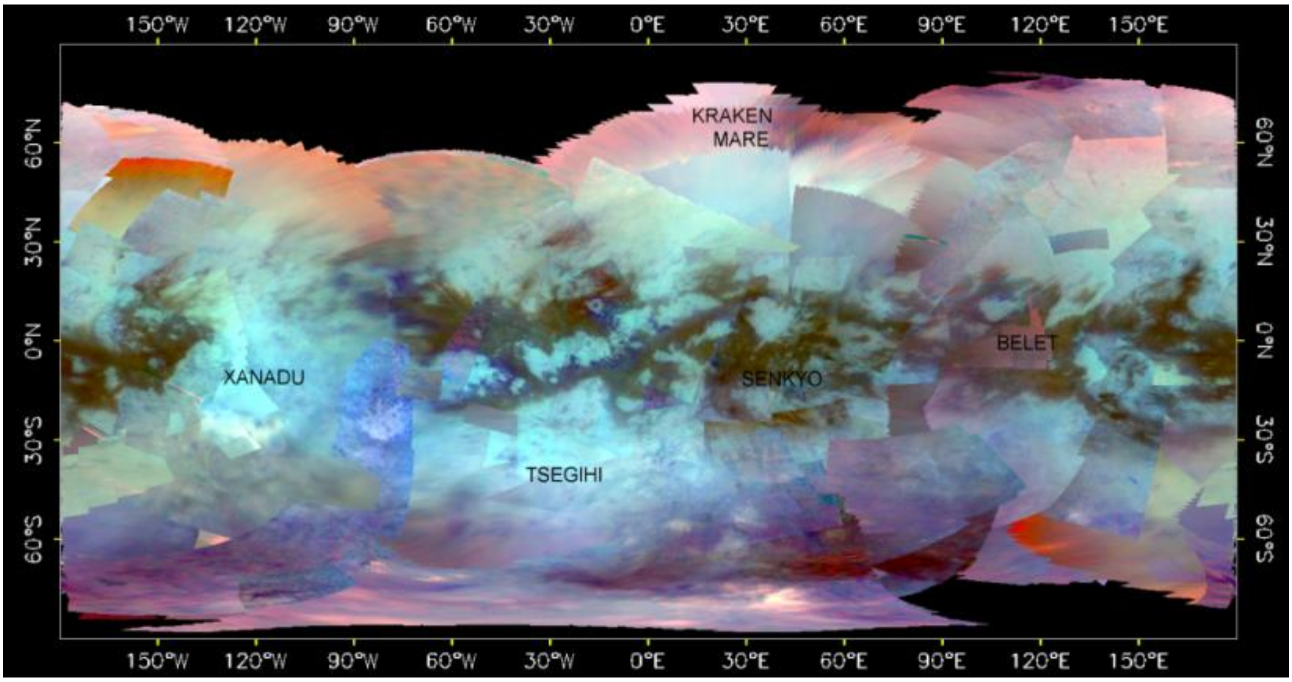
Titan, Saturn's largest moon, is the only moon in the Solar System with a dense atmosphere, mainly composed of nitrogen (95-98%) and methane (2-5%). A very active atmospheric chemistry is responsible for the production of a thick aerosol haze that settles down to its surface. Titan's atmosphere is opaque in most visible and near infrared wavelengths and makes the study of its surface particularly delicate.

Between July 2004 and September 2017, the Cassini orbiter flew over Titan and regularly acquired data on its surface and atmosphere. The James Webb Space Telescope (JWST), which will be launched in March of 2021 and begin its observation campaign in the summer of 2021, will devote part of its time to observing the solar system, including Titan. Recently, the Dragonfly mission was selected by NASA to send a drone to explore the surface and lower atmosphere of Titan as early as 2034. The JWST and Dragonfly will take over from the Cassini mission to explore Titan for the next two decades.

Cassini's observations revealed the presence on Titan of extraordinarily varied and surprisingly familiar landscapes (mountains, rivers, seas, lakes, dunes...). Most of these surface morphologies would come from formation processes involving complex and exotic climatology, based mainly on the methane cycle, similar to the hydrological cycle on Earth. Despite the remarkable success of the Cassini mission, many key questions about the nature of the atmosphere and surface of Titan, as well as their interaction, remain largely unanswered today (for example, the composition of Titan's surface, the origin of dunes, mountains, rivers, lakes and seas, still very much debated, or many aspects of its climatology, far from being fully understood, such as the distribution and seasonality of aerosol haze and methane clouds).

This thesis proposal will attempt to provide answers to these fundamental questions, drawing on Cassini's 13 years of observation of Titan and benefiting from the very first observations of the JWST.

Thus, the central objective of this work will be to adapt the radiative transfer model developed in our team (in Fortran90, C and Python languages) to produce the very first global surface reflectance map, corrected for atmospheric contributions (absorption and diffusion by gases and aerosols). This map will be based on all hyperspectral infrared images of Titan acquired by Cassini in the 0.8-5 µm spectral range (VIMS instrument) between 2004 and 2017. This represents several hundred million spectra to process and analyze. This reflectance map can then be used to identify materials that are candidates for surface composition, in comparison with laboratory spectra. Combined with Cassini/RADAR observations of dunes, mountains, rivers and seas at high spatial resolution, knowledge of the materials present on the surface will help us to better constrain the geological and climatic history that has led to the formation of these landscapes (by mechanical and/or chemical erosion by wind and/or methane rain?). The correction of atmospheric contributions will also make it possible to monitor seasonal changes in haze in relation to general atmospheric circulation. In the middle of the thesis, future observations of the JWST NIRSPEC instrument, in the same spectral range as VIMS, but at much higher spectral resolution, will help us to verify, and correct if necessary, the atmospheric inputs of the radiative transfer model and help identify the composition of Titan's surface. It will also be possible to assist in the preparation of future observations of the lower atmosphere and Titan's surface by the cameras that will equip the Dragonfly drone.



Global mosaic of Titan's surface constructed from VIMS observations (cylindrical projection; RGB colored composite with red = 5 µm, green = 2.03 µm and blue = 1.27 µm). The 3 VIMS channels are empirically corrected for the contribution of the atmosphere (Le Mouélic et al., 2012, 2019). The spatial resolution is 15 km on average, ranging from 0.5 to 1 km very locally. The atmospheric correction still needs to be improved. Some seams still appear between individual observations, indicating that these VIMS maps are not yet able to represent the "absolute" infrared reflectivity of the surface.

It should be noted that our team is associated with the VIMS and RADAR instrument teams of the Cassini spacecraft and therefore has access to all data and official processing pipelines. Our team is also involved as Co-PI in the request for Guaranteed Time for JWST observation of Titan (first observations expected at summer 2021) and is working in close collaboration with the Dragonfly scientific team.

A Master in astrophysics, planetary science, or geophysics is required by the time of starting the PhD. The following skills will be considered in the evaluation process: (1) working knowledge in planetary science (especially planetary surface and atmosphere), (2) expertise in atmospheric surface radiative transfer modeling (including model development), (3) experience of exploring datasets acquired by space missions (especially from infrared hyperspectral instruments), (4) ability to work in a team and to stimulate research as a community process. The successful applicant will benefit from a dynamic and stimulating research environment, with the possibility to interact with scientists in the IPGP team involved in radiative transfer modeling and observations of terrestrial and planetary atmospheres and surfaces, as well as French collaborators from LESIA/Observatoire de Meudon, GSMA/Université de Reims and LMD/Sorbonne Université. More broadly, the applicant will also benefit from international Cassini, JWST and Dragonfly collaborations.

Main collaborators : Antoine Lucas, Stéphane Jacquemoud and Cécile Ferrari (IPGP), Bruno Bézard, Athéna Coustenis and Benjamin Charnay (LESIA, Obs. Meudon), Pascal Rannou (GSMA, Univ. Reims), Sébastien Lebonnois (LMD, Sorbonne Université), Thomas Cornet (ESA), Christophe Sotin (JPL/Caltech, USA), Jason Barnes (Univ. Idaho, USA), Jason Soderblom (MIT, USA), Alexander Hayes (Cornell Univ., USA).